# Economic Design of Rectangular Water Tank Walls using Parabolic Arches 

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#### Abstract

Rectangular water tanks resting on ground are widely used in water and wastewater treatment plants. These tanks are usually made up of concrete. Discovery of Concrete as a construction material is the most valuable gift to mankind. Concrete behaves as a fluid at the pouring stage \& sets within a short interval after pouring. This property of a concrete is valuable \& has been exploited to the fullest by the construction industry. However, concrete is weak in taking tensile load thus, requires thicker sections \& reinforcement when subjected to tensile stresses. Primary intention of this paper is to overcome this drawback by proposing appropriate geometrical shape to the rectangular concrete water tanks so that the resultant stresses are compressive rather than tensile. This concept is applied to a large water retaining structure. Keywords: Rectangular Water Tank, Tensile Stresses, Concrete Properties, Parabolic Arch Water Tank, Compressive Stresses


## I. INTRODUCTION

Water is considered as the source of every creation and is thus a very crucial element for humans to live a healthy life. Demand for clean and safe drinking water is rising day by day. It has become necessary to store water. Water is stored generally in concrete water tanks and subsequently pumped to different areas to serve the community. Water tanks can be classified as overhead, resting on ground or underground depending on their location. The tanks can be made of steel and/or concrete. Tanks resting on ground are normally circular or rectangular in shape and are used where large quantities of water need to be stored. Overhead water tanks are used to distribute water directly through gravity flow and are normally of smaller capacity. As the overhead water tanks are open to public view, their shape is influenced by the aesthetic view in the surroundings. Water storage tanks are designed as per the provisions of IS 3370 . This code was revised in 2009. In the pre revised version, the tanks were designed using working stress method and on the philosophy of no cracking. As per IS 3370:2009, use of the limit state method has been permitted. Hence this study was undertaken to compare the design of rectangular water tank with the proposed parabolic arch tank and to analyze the cost effectiveness in terms of the quantity of steel reinforcement and concrete required.

## A. Problem Definition

The threat of global warming is for real and the world as a whole is planning united measures to combat this threat. It has been decided globally that emission of greenhouse gases needs to be controlled and that is where the concept of Carbon Credits has come in. The concept of Carbon Credit is based on a simple premise that those who pollute will have to pay \& those who reduce pollution will be rewarded. Thus, if an industry can prove that it has reduced carbon emissions, then it can claim Carbon Credits. Carbon Credits are traded worldwide at $\$ 15 /$ credit. The money comes from those who are not in position to reduce carbon emission. Coupled with the above, global water shortage, which has led to compulsive recycling of waste waters \& thus for all industries, construction \& operation of the waste water treatment plant has become mandatory.
At present, most of the wastewater treatment plants are employing aerobic treatment. Aerobic treatment requires power. As power is produced from coal, any saving in power leads to earning of Carbon Credits. If an existing aerobic wastewater treatment plant can be converted to anaerobic, then, there are two-fold advantages. As aerobic to anaerobic leads to saving power, the cost of new anaerobic treatment plant can come from Carbon Credits. Further, the operational cost will reduce substantially as there is no power requirement. Only hitch, in the above, is that the requirement of storage capacity of treatment tanks in anaerobic process is much larger than aerobic. The treatment units, thus, become costlier \& also occupy more space. It is this point that proposed research plans to address. It aims at economical design of large volume, tall concrete tanks. Water retaining rectangular tank of rectangular shape of $30 \mathrm{~m} \times 30 \mathrm{~m} \times 8 \mathrm{~m}$ depth is taken as starting point for the study. One of the most popular anaerobic treatment processes is UASB (Up-flow Anaerobic Sludge Blanket). The process requires about $7-8 \mathrm{~m}$ of depth for the reactor tank. The fundamental of this process, is that the sludge blanket itself acts as a filter $\&$ there is no further power or equipment requirement. It is expected that a large number of UASBs will be constructed in our country. This is the reason for affinity towards choosing a large rectangular tank of 7-8 m depth for study.

## II. METHODOLOGY

## A. Conventional Design

In the construction of concrete structures for the storage of liquids, the imperviousness of concrete is an important basic requirement. Aggregates and cement are to be proportioned to yield a high-quality concrete. The permeability of any uniform and thoroughly compacted concrete of given mix proportion is largely dependent on the water cement ratio. While an increase in the water cement ratio leads to an increase in inherent permeability, a highly reduced water cement ratio of a mix with a given cement content may cause compaction difficulties and thus may prove equally harmful. The mix should be designed in such a way that the resulting concrete has a high degree of imperviousness. Honeycombing and segregation of aggregates are to be minimized as these lead to defects which are responsible for leakage in water storage structures.
For a given mix made with particular materials, there is a lower limit to water-cement ratio which can be used economically on any job. It is essential to select a rich mix compatible with available aggregates, whose particle shape and grading have an important bearing on workability which must be suited to the means of compaction selected.
In the following subsection, Conventional design is presented. The vertical wall is designed as a propped cantilever. Propping action at the top of the wall is achieved by a horizontal spanning beam. The beam is in turn supported by a tie beam at every $3 \mathrm{~m} \mathrm{c} / \mathrm{c}$. The total span of the tie beams which is 30 m , is broken up into 10 span of 3 m by providing column grid. These beams are in both perpendicular directions. The supporting columns have independent footings. The wall is provided with independent continuous footing. The bottom raft of the tank is simply slab on grade with nominal thickness of 150 mm . The raft is founded on 100 mm thick PCC (plain cement concrete which acts as a levelling course). The General Arrangement drawing showing all the above details along with dimensions is included in the Appendix- I. The quantities \& cost of the major civil works are worked out \& presented in the following sub-sections.

1) Design of Tank Wall
a) Water Depth: 8m
b) Propped Cantilever Moment (negative): $34.13 \mathrm{t}-\mathrm{m}\left(\mathrm{wh}^{3} / \mathrm{l}\right)$
c) Maximum positive moment : $15.26 \mathrm{t}-\mathrm{m}\left(0.0596 * \mathrm{~h}^{3} / 2\right)$
d) Thickness Required: 100 cm (based on un-cracked design)
e) Steel Required: Water side vertical: $26.1 \mathrm{~cm}^{2}$
f) Other side vertical: $13.4 \mathrm{~cm}^{2}$
g) Horizontal steel: $10 \mathrm{~cm}^{2}$ (each face)
h) Final Design for Wall: Wall 100 cm at bottom \& 30 cm top


Figure 1 Plan of Conventional Design


Figure 2 Elevation of water tank by conventional design


Figure 3 Schematic Representation of Wall


Figure $4 \mathrm{C} / \mathrm{S}$ of propping beam
2) Design of Tank Wall Footing

Table I Details Of The Footing

| Description | Depth $(\mathrm{m})$ | Height $(\mathrm{m})$ | Width $(\mathrm{m})$ | Volume $\left(\mathrm{m}^{3}\right)$ | Weight $(\mathrm{t})$ |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Rectangular Portion of Wall | 0.3 | 8 | 1 | 2.4 | 6 |
| Triangular Portion of Wall | 0.7 | 8 | 1 | 2.8 | 7 |
| Left Portion of footing | 1.1 | 8 | 1 | - | - |
| Right Portion of footing | 1.7 | 1 | 1 | - | - |
| Footing | 3.8 | 1 | 1 | 3.8 | 9.5 |
| Water | 1.7 | 8 | 1 | 13.6 | 13.6 |
| Moment due to water | 34.13 | - | - | - | - |

Calculations (analysis) are as follows:
a) Moment due to rectangular portion of wall $(t-m)=-0.3$
b) Moment due to triangular portion of wall $(\mathrm{t}-\mathrm{m})=2.3$
c) Moment due to water $=-14.3$
d) Total Load, $\mathrm{P}(\mathrm{t})=36.10$
e) Total Moment, $\mathrm{M}(\mathrm{t}-\mathrm{m})=21.9$
f) Area, $\mathrm{A}\left(\mathrm{m}^{2}\right)=3.8$
g) Section Modulus, $\mathrm{Z}\left(\mathrm{m}^{3}\right)=2.4$
h) $\mathrm{P} / \mathrm{A}\left(\mathrm{t} / \mathrm{m}^{2}\right)=9.5$
i) $\mathrm{M} / \mathrm{Z}\left(\mathrm{t} / \mathrm{m}^{2}\right)=9.1$
j) $\mathrm{P} / \mathrm{A}+\mathrm{M} / \mathrm{Z}\left(\mathrm{t} / \mathrm{m}^{2}\right)=18.6$
k) $\mathrm{P} / \mathrm{A}-\mathrm{M} / \mathrm{Z}\left(\mathrm{t} / \mathrm{m}^{2}\right)=0.4$

Calculations (design) are as follows:
i) Moment on Footing $(\mathrm{t} / \mathrm{m})=0.6$ (from STAAD)
ii) Depth Required in $\mathrm{cm}=13.19$

Final Design Of Footing: Thickness: 100 cm , width 3800 cm ( 1700 cm water side \& 1100 cm other side)
3) Design of Propping Beam: This beam is spanning in horizontal direction with supports at every 3 m (these supports are provided by tie -frame)
a) Max. Negative Moment at Support $=\mathrm{wl}^{2} / 10=6.4 \times 3^{2} / 10=5.76 \mathrm{t}-\mathrm{m}$
b) Use $400 \times 700$ beam: steel required is $6.44 \mathrm{~cm}^{2}$.

Final design of Propping Beam : $400 \times 700$ beam, 2-20 tor $+1-16$ tor (at top) \& 3-16(tor at bottom), stirrups 8 tor at $150 \mathrm{c} / \mathrm{c}$
4) Design of Tie Beam: The beam is primarily subjected to direct tension due to reaction from propping beam. This direct tension is $6.4 \times 3=19.2 \mathrm{t}$.
a) Section required $=((19.2 \times 1000) / 6)^{1 / 2}$
b) $600 \times 600 \mathrm{~cm}$ section is sufficient.
c) Steel required $=(19.2 \times 1000) / 1500=12.8 \mathrm{~cm}^{2}$
5) Final Design of Tie Beam : $600 \times 600$ with 4 bars of 20 tor (top) \& 4 bars of 16 tor (bottom) \& 8 tor stirrups at $150 \mathrm{c} / \mathrm{c}$.
6) Design Of Columns \& Footings: Columns are required to take only dead loads of beam \& self.
a) The load to be taken by each column is $(0.6 \times 0.6 \times 3 \times 2 \times 2.5)+(0.45 \times 0.45 \times 8 \times 2.5)=9.5 \mathrm{t}$
b) Column has unsupported length of 8 m .

Final design of Column \& footings
$450 \times 450 \mathrm{~cm}, 4-20$ tor (top) $+4-16$ tor (bottom), stirrups 8 tor at 200c/c with $1500 \times 1500 \times 450$ thick sloping footing.
Based on the above design the following quantities are worked out.

Table II Excavation Quantities

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. <br> $\left(\mathrm{m}^{3}\right)$ |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | Raft | 26.8 | 26.8 | 0.3 | 1 | 215.47 |
| 2 | Wall | - | - | - | - | - |
| 3 | Wall Footing | 29.7 | 4.1 | 1.2 | 4 | 584.5 |
| 4 | Internal Column <br> Footing | 1.7 | 1.7 | 2 | 81 | 468.18 |

Table III Pcc Quantities

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total <br> $\left(\mathrm{m}^{3}\right)$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | Raft | 26.8 | 26.8 | 0.3 | 1 | 215.47 |
| 2 | Wall | - | - | - | - | - |
| 3 | Wall Footing | 29.7 | 4.1 | 1.2 | 4 | 584.5 |
| 4 | Internal Column <br> Footing | 1.7 | 1.7 | 2 | 81 | 468.18 |
| 5 | Internal Footing | - | - | - | - | - |

Table IV Concrete (M25) Quantities

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total $\left(\mathrm{m}^{3}\right)$ |
| :--- | :--- | :---: | :---: | :---: | :---: | :--- |
| 1 | Raft | 26.6 | 26.6 | 0.15 | 1 | 106.13 |
| 2 | Wall | 31 | 0.65 | 8 | 4 | 644.8 |
| 3 | Wall Footing | 29.7 | 3.9 | 1 | 4 | 463.32 |
| 4 | Top beam | 30.7 | 0.4 | 0.7 | 4 | 34.384 |
| 5 | Tie b1 | 31 | 0.6 | 0.6 | 18 | 200.88 |
| 6 | Tie b2 | - | - | - | - | - |
| 7 | Tie b3 | - | - | - | - | - |
| 8 | Internal column | 8 | 0.45 | 0.45 | 81 | 131.22 |
| 9 | Internal footings | 1.5 | 1.5 | 0.45 | 81 | 82.013 |

Table V Plane Shuttering Details

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total (m $\left.{ }^{3}\right)$ |
| :--- | :--- | :---: | :---: | :---: | :---: | :--- |
| 1 | Raft | 106.4 | 1 | 0.15 | 1 | 15.96 |
| 2 | Wall | 31 | 0.65 | 16 | 4 | 1289.4 |
| 3 | Wall Footing | 29.7 | 2 | 1 | 4 | 237.6 |
| 4 | Top beam | 30.7 | 1 | 1.8 | 4 | 221.04 |
| 5 | Tie b1 | 31 | 1.8 | 1 | 18 | 1004.4 |
| 6 | Tie b2 | - | - | - | - | - |
| 7 | Tie b3 | - | - | - | - | - |
| 8 | Internal column | 8 | 1.8 | 1 | 81 | 1166.4 |
| 9 | Internal footings | 6 | 1 | 0.45 | 81 | 218.70 |

Table VI Total Quantities And Cost

| No. | Description | Total Quantity | Rate(Rs/unit) | Cost (Rs) |
| :--- | :--- | :--- | :--- | :--- |
| 1 | Excavation | 799.97 | 100 | 79996.8 |
| 2 | PCC (M100) | 120.53 | 3000 | 361596 |
| 3 | M25 Concrete | 1580.74 | 4200 | 6639100 |
| 4 | Plane Shuttering | 3935.00 | 250 | 983750 |
| 5 | Curved Shuttering | - | - | - |
| 6 | Reinforcement Steel | 132.83 | 58000 | 7704314 |

## B. Proposed Innovative Design

In the following sub-section, an innovative approach is proposed. The vertical wall is made of a series of parabolic two hinged arches of 3 m span. Thus, in plan on each side, 10 arches are seen. Each arch has a cross section of 1 mx 0.1 m . Bottom. Most arches are designed and the same design is followed till the top of the tank. Property of two hinged parabolic arch is that, both moment \& radial shear is zero at every section. Thus, arch needs to be designed for direct compressive force only. Hence, as shown in appendix -2 , the 10 cm thickness is sufficient (as against average thickness of 65 cm required in the conventional design). At the arch supports out of the two reactions, reaction along the wall gets cancelled (except for the end arches) while reaction perpendicular to the wall gets added. Columns are provided to cater for these horizontal reactions. The columns are part of frame which extends across the two opposite walls.


Figure 5 Plan of the proposed design of water tank
It is proposed to use parabolic shape for vertical wall. After number of trials parabolic arch which obeys $y=0.3-\left(4 x 0.3 / 3^{2}\right)(x-$ $1.5)^{2}$ is proposed.
Each arch has span of $3 \mathrm{~m} \&$ rise of 0.3 m . On each 30 m side there will be 10 such arches. Arches are considered as two hinged arches \& thus for uniformly distributed load at any section of the arch moment \& radial shear is zero \& thus cross section is subjected to only axial compression. Table VII gives the values of axial force at every 0.1 m .


Figure 6 Schematic Loading diagram of the parabolic arch

Table VII Axial Force Values At Every 0.1 M

| x | y | $\tan \theta$ | $\theta$ | $\operatorname{Sin} \theta$ | $\operatorname{Cos} \theta$ | $\mathrm{V}(\mathrm{t})$ | $\mathrm{H}(\mathrm{t})$ | Axial <br> Force $(\mathrm{t})$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 0 | 0 | 0.40 | 21.83 | 0.37 | 0.9283 | 12 | 30.00 | 32.31 |
| 0.1 | 0.04 | 0.37 | 20.50 | 0.35 | 0.9367 | 11.2 | 30.00 | 32.02 |
| 0.2 | 0.07 | 0.35 | 19.14 | 0.33 | 0.9447 | 10.4 | 30.00 | 31.75 |
| 0.3 | 0.11 | 0.32 | 17.77 | 0.31 | 0.9523 | 9.6 | 30.00 | 31.50 |
| 0.4 | 0.14 | 0.29 | 16.37 | 0.28 | 0.9595 | 8.8 | 30.00 | 31.26 |
| 0.5 | 0.17 | 0.27 | 14.95 | 0.26 | 0.9662 | 8 | 30.00 | 31.05 |
| 0.6 | 0.19 | 0.24 | 13.51 | 0.23 | 0.9723 | 7.2 | 30.00 | 30.85 |
| 0.7 | 0.21 | 0.21 | 12.06 | 0.21 | 0.9779 | 6.4 | 30.00 | 30.68 |
| 0.8 | 0.23 | 0.19 | 10.59 | 0.18 | 0.9830 | 5.6 | 30.00 | 30.52 |
| 0.9 | 0.25 | 0.16 | 9.10 | 0.16 | 0.9874 | 4.8 | 30.00 | 30.38 |
| 1 | 0.27 | 0.13 | 7.60 | 0.13 | 0.9912 | 4 | 30.00 | 30.27 |
| 1.1 | 0.28 | 0.11 | 6.10 | 0.11 | 0.9943 | 3.2 | 30.00 | 30.17 |
| 1.2 | 0.29 | 0.08 | 4.58 | 0.08 | 0.9968 | 2.4 | 30.00 | 30.10 |
| 1.3 | 0.29 | 0.05 | 3.06 | 0.05 | 0.9986 | 1.6 | 30.00 | 30.04 |
| 1.4 | 0.30 | 0.03 | 1.53 | 0.03 | 0.9996 | 0.8 | 30.00 | 30.01 |
| 1.5 | 0 | 0.00 | 0.00 | 0.00 | 1.0000 | 0 | 30.00 | 30.00 |

In the above table values of Axial Force experienced by the arch section is given. The distributed load $w$ is taken as $8 t / \mathrm{m}^{2}$ which is at bottom 1 m of the tank.
As can be seen from the above table the maximum axial force experienced by the section is 32.31 t . (The size of the section is $100 \mathrm{~cm} \times 10 \mathrm{~cm}$ ) This gives capacity of 60 t (taking M25 concrete).
Thus the 10 cm thickness is more than sufficient to take this compressive load. The gaps created due to arches are filled with lean concrete or brickwork so that the assumed load condition (uniformly distributed) is achieved.
Thus, parabolic arches of 10 cm thick, 3 m span $\& 0.3 \mathrm{~m}$ rise are provided along the sides of the tank. Thus there are 10 arches per/side adding up to 40 arches for the tank.
At the arch supports out of the two reactions ( $\mathrm{H} \& \mathrm{~V}$ ), reaction along the wall ( H ) gets cancelled (except for the end arches) while the reaction perpendicular to the wall $(\mathrm{V})$ gets added.
Columns are provided to cater for these horizontal reactions. The columns are made part of frame which extends across the two opposite walls.
Typical such frame is analyzed using STAAD. The input file for STAAD is as following:
STAAD PRO
START JOB INFORMATION
ENGINEER DATE 30-0ct-08
END JOB INFORMATION
INPUT WIDTH 79
UNIT METER MTON
JOINT COORDINATES
1000; 2020 0; $3040 ; 4080$;
MEMBER INCIDENCES
112; 22 3; 33 4;
DEFINE MATERIAL START
ISOTROPIC CONCRETE
E 2.21467e+006
POISSON 0.17
DENSITY 2.40262
ALPHA 1e-005

DAMP 0.05
END DEFINE MATERIAL
MEMBER PROPERTY AMERICAN
1 TO 3 PRIS YD 0.6 ZD 0.3
CONSTANTS
MATERIAL CONCRETE MEMB 1 TO 3
SUPPORTS
I FIXED
2 TO 4 PINNED
LOAD 1 LOAD 1
MEMBER LOAD
1 TRAP GX 241802
2 TRAP GX 181202
3 TRAP GX 120.00104
PERFORM ANALYSIS
FINISH


Figure 7 Hydrostatic Static Loading Diagram on Tank Wall
The maximum negative bending moment obtained from the STAAD is $9.83 \mathrm{t}-\mathrm{m}$ for which the column $\&$ footing is designed.
The reactions induce tension in tie beams (tie beams are at three levels). Internal columns are only subjected to self-weight.

1) Design of Tie Beam
a) Induced tension $=35.14 \mathrm{t}$
b) Area required $=((35.13 \times 1000) / 7)^{1 / 2}=70.84 \mathrm{~cm} \times 70.8 \mathrm{~cm}$ (M 30 Concrete)
c) Area required $=((31.75 \times 1000) / 7)^{1 / 2}=67.3 \mathrm{~cm} \times 67.3 \mathrm{~cm}$ (M 30 Concrete)
d) Area required $=((5.5 \times 1000) / 6)^{1 / 2}=30.3 \mathrm{~cm} \times 30.3 \mathrm{~cm}$ (M 25 Concrete)

Therefore, three sizes adopted for three level tie beams are $75 \mathrm{~cm} \times 75 \mathrm{~cm}, 70 \mathrm{~cm} \times 70 \mathrm{~cm} \& 35 \mathrm{~cm} \times 35 \mathrm{~cm}$.
2) Design Of Column At The Junction Of Arches
a) $\mathrm{M}=9.83 \mathrm{t}-\mathrm{m}$ (from STAAD)
b) $\mathrm{P}=(0.3 \times 0.6 \times 2.5) \times 8=3.6 \mathrm{t}$, say 4 t ,
c) $\mathrm{B}=300 \mathrm{~mm}, \mathrm{D}=600 \mathrm{~mm}$
d) $\mathrm{Pu}=4 \times 1.5=6 \mathrm{t}$
e) $\mathrm{Mu}=9.83 \times 1.5=14.75 \mathrm{t}-\mathrm{m}$
f) $\mathrm{Pu} / \mathrm{f}_{\mathrm{ck}} \times \mathrm{B} \times \mathrm{D}=0.0133$
g) $\mathrm{Mu} / \mathrm{f}_{\mathrm{ck}} \times \mathrm{B} \times \mathrm{D} 2=0.0546$

Refer Chart 44 of IS456 - Design Aid
h) 13.5 cm 2 of steel required

Final Design of Column: $300 \times 600,8$-16tor \& 8 tor stirrups at 200c/c.
3) Design Of Footing Of Column At The Junction Of Arches
a) Size $1.5 \mathrm{~m} \times 2.75 \mathrm{~m}$
b) $\mathrm{P}=1.5 \times 2.75 \times 2.5 \times 2=20.63 \mathrm{t}$
c) $\mathrm{M}=10 \mathrm{t}-\mathrm{m}$
d) Area $=4.13 \mathrm{~m}^{2}$
e) $\mathrm{Z}=1.89 \mathrm{~m}^{2}$
f) $\mathrm{P} / \mathrm{A}=5 \mathrm{t} / \mathrm{m}^{2}$
g) $\mathrm{M} / \mathrm{Z}=5.3 \mathrm{t} / \mathrm{m}^{2}$

Final Design of Footing: $1.5 \mathrm{~m} \times 2.75 \mathrm{~m} \times 0.45 \mathrm{~m}, 10$ tor at $150 \mathrm{c} / \mathrm{c}$ both ways.
Thus, summary of design of various structural elements for this design is as under:
i) Arch: 100 mm thickness
ii) Outer Column: $300 \mathrm{~mm} \times 600 \mathrm{~mm}$
iii) Outer Footings: $1500 \mathrm{~mm} \times 2750 \mathrm{~mm} \times 450 \mathrm{~mm}$
iv) Internal Columns: $300 \mathrm{~mm} \times 300 \mathrm{~mm}$
v) Internal Footings: $1250 \mathrm{~mm} \times 1250 \mathrm{~mm} \times 450 \mathrm{~mm}$
vi) Tie Beam level 1:350mm $\times 350 \mathrm{~mm}$
vii) Tie Beam level 2: $700 \mathrm{~mm} \times 700 \mathrm{~mm}$
viii) Tie Beam level 3: $750 \mathrm{~mm} \times 750 \mathrm{~mm}$
ix) Bottom raft thickness -150 mm (slab on grade)

Based on the above design the following quantities are worked out.
Table VIII Excavation Quantities

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total $\left(\mathrm{m}^{3}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Raft | 30 | 30 | 0.5 | 1 | 450 |
| 2 | Arch Wall | - | - | - | - | - |
| 3 | External Columns | - | - | - | - | - |
| 4 | External footings | 1.7 | 3 | 2.6 | 44 | 583.44 |
| 5 | Internal footings | 1.5 | 1.5 | 2.6 | 81 | 473.85 |

Table IX PCC Quantites

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total $\left(\mathrm{m}^{3}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Raft | 30 | 30 | 0.1 | 1 | 90 |
| 2 | Arch Wall | - | - | - | - | - |
| 3 | Vertical Columns | - | - | - | - | - |
| 4 | Footings | 1.7 | 3 | 0.1 | 44 | 22.44 |
| 5 | Internal footings | 1.5 | 1.5 | 0.1 | 81 | 18.23 |

Table X Concrete M25 Quantities

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total $\left(\mathrm{m}^{3}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Raft | 30 | 30 | 0.15 | 1 | 135.00 |
| 2 | Wall | 1.1 | 0.1 | 8 | 40 | 35.2 |
| 3 | External Columns | 8 | 0.3 | 0.6 | 44 | 63.36 |
| 4 | External Footings | 1.5 | 2.75 | 0.45 | 44 | 81.675 |
| 5 | Tie b1 | 30 | 0.35 | 0.35 | 18 | 66.15 |
| 6 | Tie b2 | 30 | 0.7 | 0.7 | 18 | 264.6 |
| 7 | Tie b3 | 30 | 0.75 | 0.75 | 18 | 303.75 |
| 8 | Internal column | 8 | 0.3 | 0.3 | 81 | 58.32 |
| 9 | Internal footings | 1.25 | 1.25 | 0.45 | 81 | 56.95 |

Table XI Plane Shuttering Quantities

| No. | Description | Length <br> $(\mathrm{m})$ | Breadth <br> $(\mathrm{m})$ | Depth <br> $(\mathrm{m})$ | Nos. | Total $\left(\mathrm{m}^{3}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Raft | 120 | 1 | 0.15 | 1 | 18 |
| 2 | Wall | - | - | - | - | - |
| 3 | External Columns | 8 | 1.8 | 1 | 44 | 633.6 |
| 4 | External Footings | 8.5 | 1 | 0.45 | 44 | 168.3 |
| 5 | Tie b1 | 30 | 0.75 | 1 | 18 | 405 |
| 6 | Tie b2 | 30 | 0.75 | 1 | 18 | 405 |
| 7 | Tie b3 | 30 | 0.75 | 1 | 18 | 405 |
| 8 | Internal column | 8 | 1.2 | 1 | 81 | 777.6 |
| 9 | Internal footings | 6 | 0.45 | 1 | 81 | 218.70 |

Table XII Total Quantity \& Cost

| No. | Description | Total | Rate (Rs/unit) | Cost (Rs) |
| :---: | :---: | :---: | :---: | :---: |
| 1 | Excavation \& refiling | $1033.44 \mathrm{~m}^{3}$ | 100 | 103344 |
| 2 | PCC (M100) | $112.44 \mathrm{~m}^{3}$ | 3000 | 337320 |
| 3 | M25 Concrete | $1008.06 \mathrm{~m}^{3}$ | 4200 | 4233831 |
| 4 | Plane Shuttering | $2812.50 \mathrm{~m}^{2}$ | 250 | 703125 |
| 5 | Curved Shuttering | $704.00 \mathrm{~m}^{2}$ | 1000 | 704000 |
| 6 | Reinforcement Steel | 81.82 t | 58000 | 4745697 |
| 7 | Lean concrete | $100.00 \mathrm{~m}^{3}$ | 2000 | 200000 |
| TOTAL |  |  |  |  |

## III.RESULTS

Results of both approaches are presented below. In the two tables provided, the quantities \& cost obtained from conventional \& innovative designs are compared.
All the quantities and the subsequent costs are taken as per current market data.
TABLE XIII
Quantity comparison between conventional and innovative design

| No. | Description | Conventional Design | Proposed Innovative <br> Design |
| ---: | :--- | :--- | :--- |
| 1 | Excavation | $800 \mathrm{~m}^{3}$ | $1035 \mathrm{~m}^{3}$ |
| 2 | PCC | $120 \mathrm{~m}^{3}$ | $115 \mathrm{~m}^{3}$ |
| 3 | M25 Concrete | $1580 \mathrm{~m}^{3}$ | $1008 \mathrm{~m}^{3}$ |
| 4 | Steel | 133 tons | 82 tons |
| 5 | Plane Shuttering | $3940 \mathrm{~m}^{2}$ | $2815 \mathrm{~m}^{2}$ |
| 6 | Curved Shuttering | - | $705 \mathrm{~m}^{2}$ |

Table XIV
Cost comparison between conventional and innovative design

| No | Description | Conventional Design | Proposed Innovative Design |
| :--- | :--- | :--- | :--- |
| 1 | Excavation | Rs.80,000 | Rs. 1,03,500 |
| 2 | PCC | Rs.3,60,000 | Rs. 3,45,000 |
| 3 | M25 Concrete | Rs. 66,36,000 | Rs. 42,33,600 |
| 4 | Steel | Rs. 77,14,000 | Rs. 47,56,000 |
| 5 | Plane Shuttering | Rs. 9,85,000 | Rs. 7,37,500 |
| 6 | Curved Shuttering | - | Rs. 7,05,000 |
| 7 | Lean Concrete | - | Rs. 2,00,000 |
|  | Total | Rs. 1,57,75,000/- | Rs. 1,10,80,600/- |

## IV.CONCLUSIONS

As presented in Table XIII and Table XIV, use of arches in design of walls leads to a cost reduction of Rs 46,94,400. The innovative design shows a saving of up to $30 \%$. In the new approach, the moment and shear loading was converted to axial compression to utilize the full potential of concrete. A $36 \%$ reduction in concrete was observed in the innovative design, which in turn leads to a lower carbon foot print. The results were encouraging as the thickness of wall reduced to 10 cm from average of 65 cm in conventional design. Further, there is scope for thinking on how best to handle the horizontal thrust at the supports of arches. There is scope for trying out capacities and bringing the design to practically adaptable simplicity.

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